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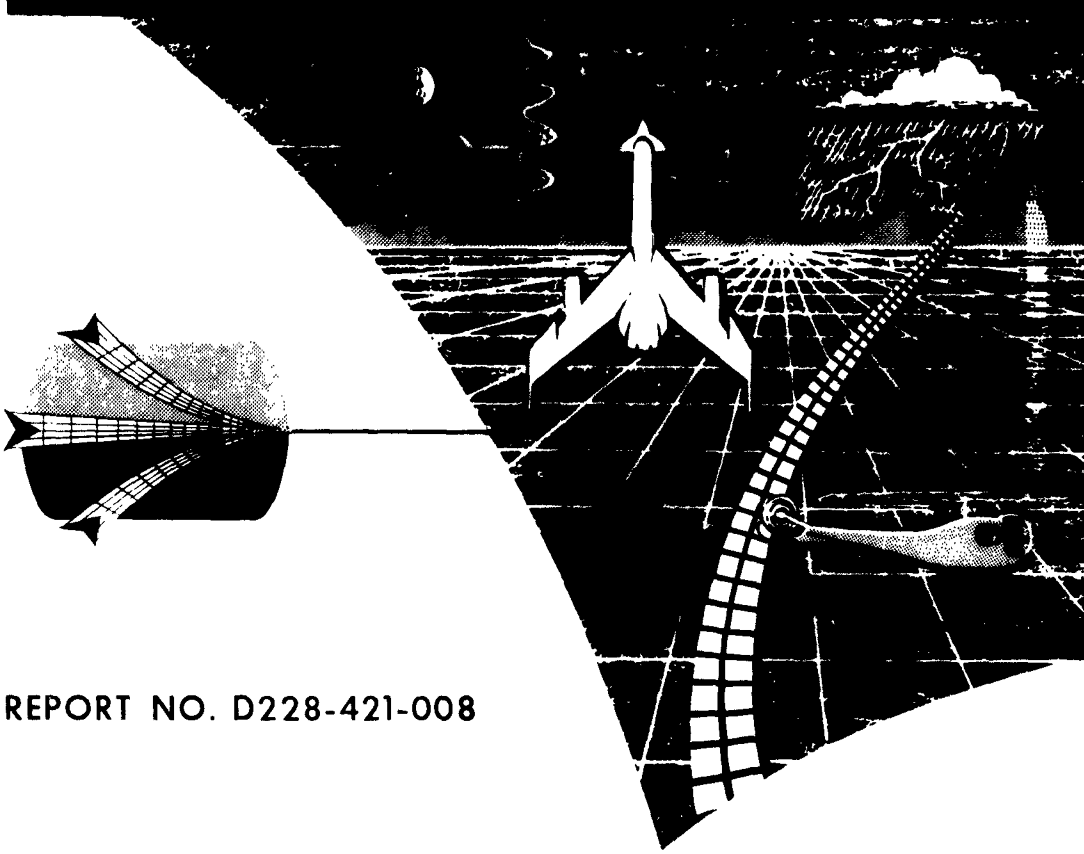
ANIP

ARMY-NAVY INSTRUMENTATION PROGRAM

AN EVALUATION OF A GRID ENCODEMENT OF THE GROUND PLANE AS A HELICOPTER HOVERING DISPLAY



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AN EVALUATION OF A GRID ENCODEMENT OF THE GROUND PLANE AS A HELICOPTER HOVERING DISPLAY

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ARMY-NAVY INSTRUMENTATION PROGRAM
CONTRACT Nonr 1670(00)

This report presents work which was performed under the Army-Navy Instrumentation Program, a research and development program directed by the United States Navy Office of Naval Research. Special guidance is provided to the program from the Army Signal Corps, the Office of Naval Research and the Bureau of Weapons through an organization known as the Joint Instrumentation Working Group. The group is currently composed of the following representatives:

U. S. Navy Office of Naval Research
- LCDR R. N. de Callies

U. S. Navy Bureau of Weapons
- CDR J. Perry

U. S. Army Office of the Chief Signal Officer
- Mr. W. C. Robinson

The paramount objective of the ANIP program is to simplify and to improve the relationships between man (the operator) and the machine he controls to provide the man-machine complex with all-visibility operating capabilities.

The program under which this study was performed is coordinated by the Electronics Department of Bell Helicopter Company, a Division of Bell Aerospace Corporation, a Textron company, and operates under ANIP Contract Nonr 1670(00). Bell Helicopter Company is designated as industry coordinator to conduct the ANIP program with special reference to flight vehicles with steep gradient capabilities (rotary wing, VTOL, ground effect machines, etc.).

ABSTRACT

This study was undertaken to determine the effectiveness of the contact analog display when used as a hovering display for the helicopter. The study compared hovering performance on the analog display with performance under contact conditions.

Ten helicopter pilots were tested on the analog display and under contact conditions. "Contact" in this study was defined as being a real world view of the same visual angle as was represented by the analog display. Upon completion of their test trials on the analog display, all subjects lifted the helicopter off to a hover and landed unassisted while using the grid perspective display.

Data were collected on the pilots' ability to hold altitude, heading, and deviations in fore-and-aft and laterally from a point on the ground. Data were summarized through use of (1) a constant error, and (2) RMS, "variation about the standard". The constant error analysis showed that the constant error did not differ significantly from zero, i.e., there was no offset bias in the system performance. With respect to the total RMS scores, the performances were significantly more variable on control of fore-and-aft translations and heading deviations when the subjects were operating with the contact analog grid display but were not different on control of altitude and lateral deviations. An analysis of the sixth or last trial for the two conditions showed that the control of altitude was significantly more variable on the contact condition than on the instrument condition, whereas in the control of lateral and fore-and-aft translation the variance is greater on the instrument condition. Although statistically significant differences were found, these differ-

ences were not of a magnitude such as to constitute a significant practical amount of error.

This demonstrated that the experienced subjects as well as relatively inexperienced subjects were able to lift the helicopter from the ground, hover it and return it to the landing position, unaided, through use of the analog display. It was also found that experienced pilots could incorporate and use at least one of the six dimensions of required information when this dimension (altitude) is not encoded as a direct analog of the real world perspective view.

TABLE OF CONTENTS

INTRODUCTION

The hovering mode of flight is basic to all helicopter missions, and therefore the accomplishment of this mode under instrument flight conditions is of critical importance. Consequently, the presentation of this information to the pilot in a form which allows him to perform the hover under conditions of greatly reduced visibility has been of prime concern within the rotary wing ANIP program.

In order to hover his aircraft successfully the helicopter pilot must stabilize the vehicle, i.e., null pitch, roll and yaw deviations, and he must correct for deviations from a designated position in space, i.e., he must null deviations as they occur along the X, Y and Z axes of three-dimensional space. He is thus faced with the problem of discriminating positional changes in six dimensions. In order to successfully hover the aircraft he undoubtedly must also discriminate rates of change along and about these dimensions, and it is very probable that the experienced pilot detects acceleration cues with respect to at least some of the dimensions. It is apparent from an analysis of the vehicle system and the task set for it that these types of deviations must be discriminated and controlled. It is apparent also that the task can be very successfully accomplished by the experienced pilot under contact flight conditions.

We know what is required of being controlled and we can set limits within which the several dimensions should be controlled. Our real problem lies in <u>encoding</u> or <u>transducing</u> the physical measurement of deviations or errors along these dimensions into a form which can be used successfully by the pilot when he cannot view the contact world. A simple and straightforward way of transducing the information, from the equipment point of view, would be to drive a pointer on a circular dial for each of the sensed parameters. Thus all of the physically measured information of positional changes plus their derivatives could be presented on the instrument panel with six instruments representing pitch, roll, yaw, X, Y and Z respectively. If we wished to give the pilot information as to the rates of movement along the six dimensions in more clearly readable form we could add six more dials, each of which presented as a position of a needle the rate at which deviations along each of the dimensions was occurring. Similarly, acceleration information could be added. With 18 separate instruments we could then bring into the cockpit a portion of the information the pilot has available to him during contact flight, and of course in the form of 18 separate instruments he could not successfully discriminate and control all of the dimensions without extensive practice, if indeed he could ever successfully master the task.

This little exercise has been engaged in to illustrate the necessity for somehow integrating <u>within the information display</u> all the separate pieces of information required for hovering. It may be clarifying in this regard to distinguish between "perceptual" integration and "cognitive" integration. We would wish the information to be integrated at the perceptual level and not be required of being integrated at the cognitive level. The presenting of separate pieces of information, as with the several circular dials, would require the determination of relationships among the many indices and their meaning for control at the central or cognitive level - a function at which the human organism does not appear to be particularly adept.

When we look for a display of information which is integrated at the perceptual level we look to the one which allows the pilot to successfully accomplish the task - the contact world scene. He can hover the helicopter using this information since, in point of fact, the dynamics of the helicopter are what they are because they can be controlled by reference to the "real world" scene. If the helicopter could not have been controlled by reference to this view, it simply would not have evolved in its present form.

The real world scene then provides the compound from which we must liberate the essential constituents (cues) for presentation during instrument flight. The knotty problem is how to encode the information contained in this real world scene in a usable and practical display.

In seeking solutions to the problem, several questions arise: what size display is adequate, what shape display is most useful, and what should be the content of the display.

The ANIP investigations, aimed at answering these questions, began with simple tests in which the display under test was back-projected upon a translucent screen as a static image to which the subject responded by simply pressing one of three buttons [1,2]. The size, shape and content of the displays were varied to determine their effect upon display interpretation. However, the content of the display, i.e., how the information was encoded, tended to influence interpretation. Very impoverished encodings of the ground plane, e.g., a simple horizon line, were not as interpretable as were more enriched displays, e.g., a grid pattern or real world photograph. These tests indicated that a wide range of means of encoding the ground plane were equally acceptable, a finding which has tended to be borne out in later dynamic tests.

The static tests were conducted as "first look" screening devices to be followed by more realistic and representative dynamic tests. Static tests are inexpensive and can serve to bring out gross deficiencies in display design before the equipment (often expensive and complex) is available for more definitive tests. The static tests were supplemented by tests in a fixed base simulator (the dynamic simulator had not been completed at the time) [3]. These tests supported the contention that the task of hovering the helicopter could be accomplished through use of a display which encoded the ground plane as a grid pattern and which moved in geometric correspondence with the ground plane.

As a further test of the feasibility of using a small segment of the real world view as a display, data were collected to determine whether helicopter pilots could hover their aircraft using a restricted view of the real world [4]. These tests showed that the pilot's view of the real world could be restricted to a solid viewing angle of 30° and still hover the helicopter as precisely as with the "full bubble" view.

When a real world scene is transposed onto a two-dimensional surface, the cues to depth perception arising from binocular viewing the real world scene are lost. To secure an estimate of the effect of such a loss on hovering performance, helicopter pilots were tested as to their ability to hover the aircraft using only monocular vision[5]. With only monocular cues, performance was degraded from binocular performance; however, the pilots were able to successfully accomplish the task.

The evidence from all of the tests described above indicated that the pilot would be able to hover the helicopter successfully using a display in which the real world ground plane was encoded as a grid plane, the display representing a 30° solid viewing angle, and in which only monocular cues to depth were present. This report gives the details of the test of this conclusion in Research Helicopter Number 1 (RH-1) and serves to compare performance on such a display to performance using the real world contact cues.

METHOD

Subjects

Ten Bell Helicopter test pilots were used as subjects. All had been instrument qualified; however, only three were current in instrument proficiency. Their ages ranged from 28 - 42 with an average age of 37 years. Each subject served in two test sessions as described below.

Equipment

A Navy HTL-7 (RH-1) helicopter (Figure 1) was used as the flying test bed.

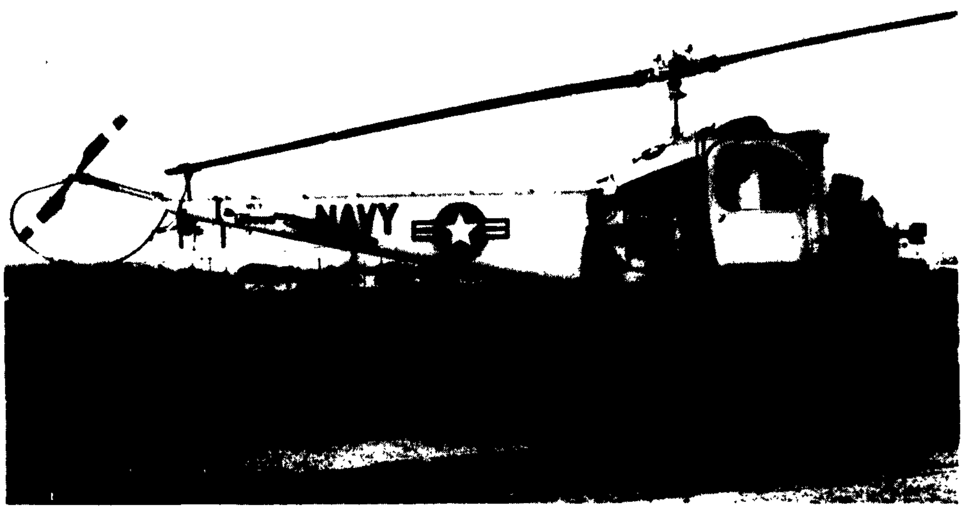


FIGURE 1.

Navy HTL-7 (RH-1) Helicopter Used in Comparing Performance on the Contact Analog with "Contact" Performance.

Installed in this aircraft was an APN-97 doppler radar ground speed sensor, an APN-22 sonic altimeter, an electromechanical ground plane generator (shown in an artist's sketch in Figure 2), a vertical altimeter display (Figure 3), and an Autonetics combiner screen. The doppler radar sensed deviations in fore and aft translation and lateral translation, the resulting signals being used to drive the belts in the ground plane generator in X and Y. The dual antenna was installed under the "chin" of the helicopter as shown in Figure 1. The APN-22 sonic altimeter sensed deviations of the helicopter along the vertical spatial axis (altitude) and its signals were used to drive the vertical altimeter display.

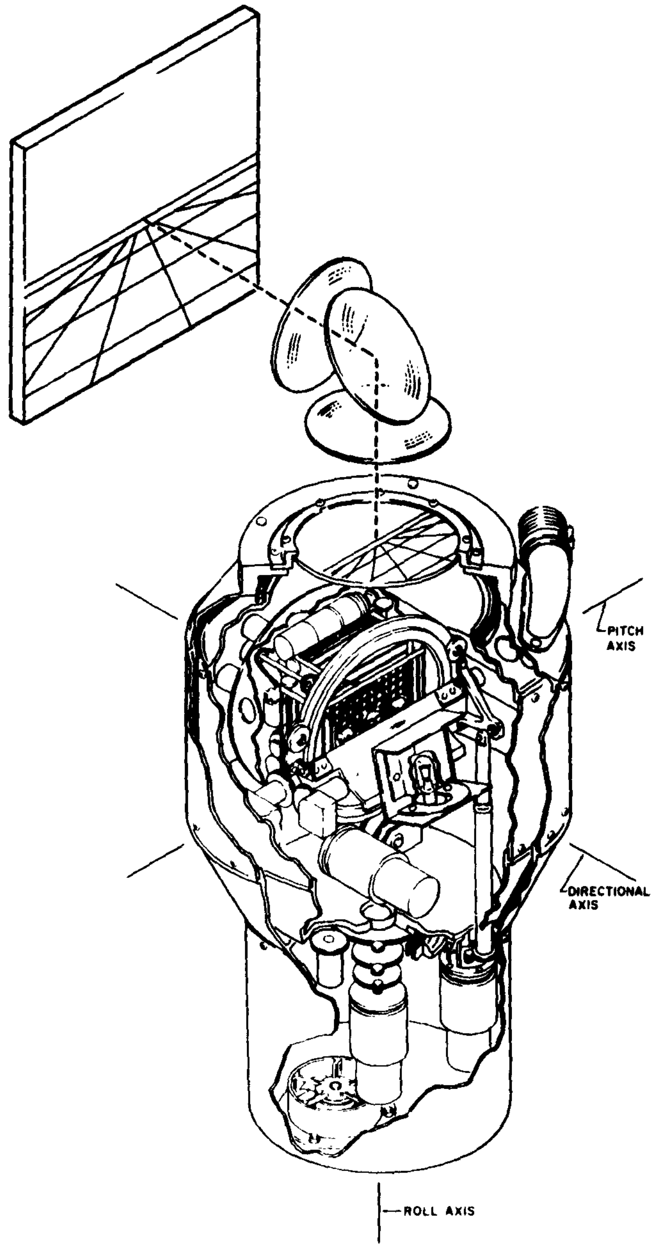


FIGURE 2. Ground plane generator for producing shadowgraph of a grid pattern with perspective.

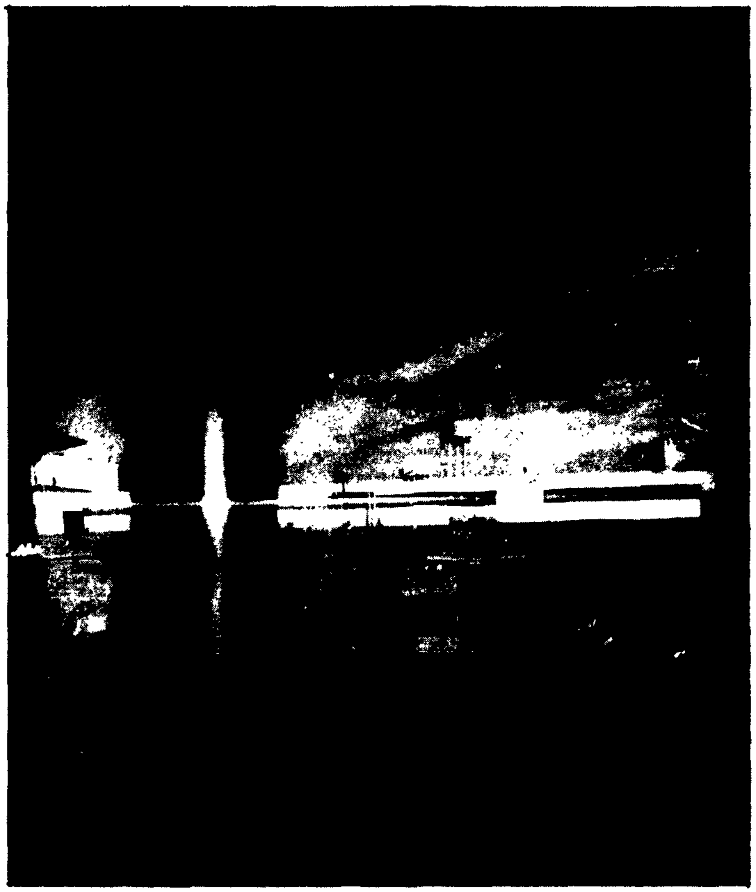


FIGURE 3. The installation of the altitude display on the left side of the vertical display.

Due to design limitations of the altitude mechanism in the ground plane generator a discriminable change in the size of the grid squares could not be produced, creating the need for a separate altitude display. The altitude display was designed so that it gave accurate qualitative (precise although non-quantitative) information. When the index was positioned at the narrow "waist" of the display (Figure 3) the skids of the helicopter were 7 ft above the ground with the total usable range of the instrument being approximately 16 feet. This type of display was used in keeping with the philosophy of the Army Navy Instrumentation Program. It presented altitude information in a symbolic analogue form. Its movement correlated with the movement of the collective stick.

The ground plane generator produced a shadowgraph of a grid with a unique pattern at one position of the belts. This pattern was used as the hovering

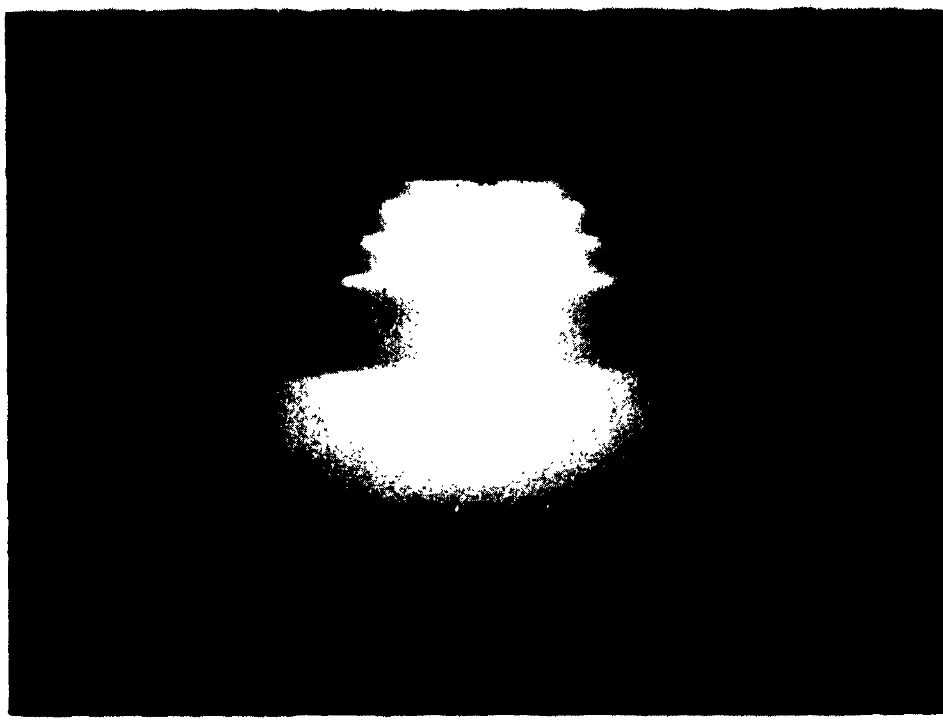


FIGURE 4. The hovering symbol was the large square of light, zero position being physically in the center of the lower half of the display.

position symbol (Figure 4) which the subjects were to keep in the center of the display. To produce this pattern it was found that a belt of wide slats with one slat missing could be used with a belt of narrow slats also with one slat missing. The wide-slatted belt was oriented along the longitudinal axis of the ship for the hovering task and the narrow-slatted belt was oriented along the horizontal axis. The ground plane generator also produced a wide-band horizon line which had a bright distinct top with a decreasing brilliance toward the bottom which tended to blend into the ground plane symbol. The horizon image generating mechanism was mounted on the part holding the grid belt and heading mechanism, thus tying the two symbols together in pitch and roll. A Lear Master Attitude Reference Gyro System supplied the signals for driving the display mechanism in pitch and roll. Heading was discriminated from the orientation of the grid lines and was driven by an MA-1 compass system.

The projection technique employed to produce the display image used a point source light to produce a shadow of the grid pattern on a ground glass screen. An aerial image of the pattern was erected through a simple lens and 90° mirror.(Figure 5).

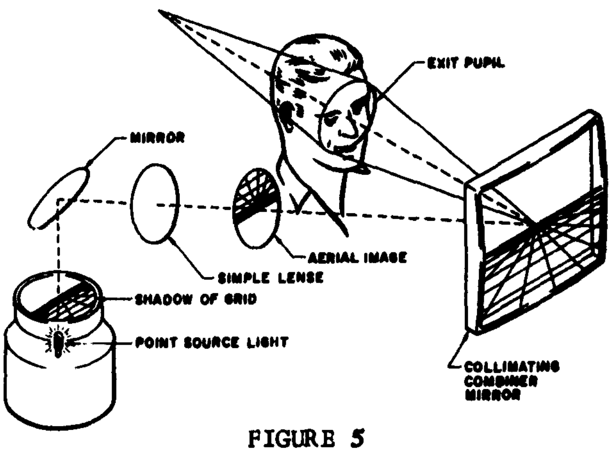


FIGURE 5

The Projection Technique Used to Produce and Display the Grid Pattern

The combiner mirror, used as the display medium, collimated the aerial image for viewing at the exit pupil. The size of the exit pupil (knothole) was dictated by the size of the optics used, in this case the diameter of the exit pupil was 4-1/4 inches in diameter, 24-5/8 inches from the aft surface of the combiner mirror. Pitch indices were attached to the sides of the combiner screen and were adjustable individually. They can be seen at the sides of the display frame, Figure 3.

The subject's side of the bubble was lined with amber acetate (Figure 6). A section of amber acetate was positioned between the two pilot seats and over a portion of the window in the subject's door so that with modified complementary-blue goggles the outside world was completely blacked out. Communication with the subject was accomplished through use of the ship's intercommunications system.

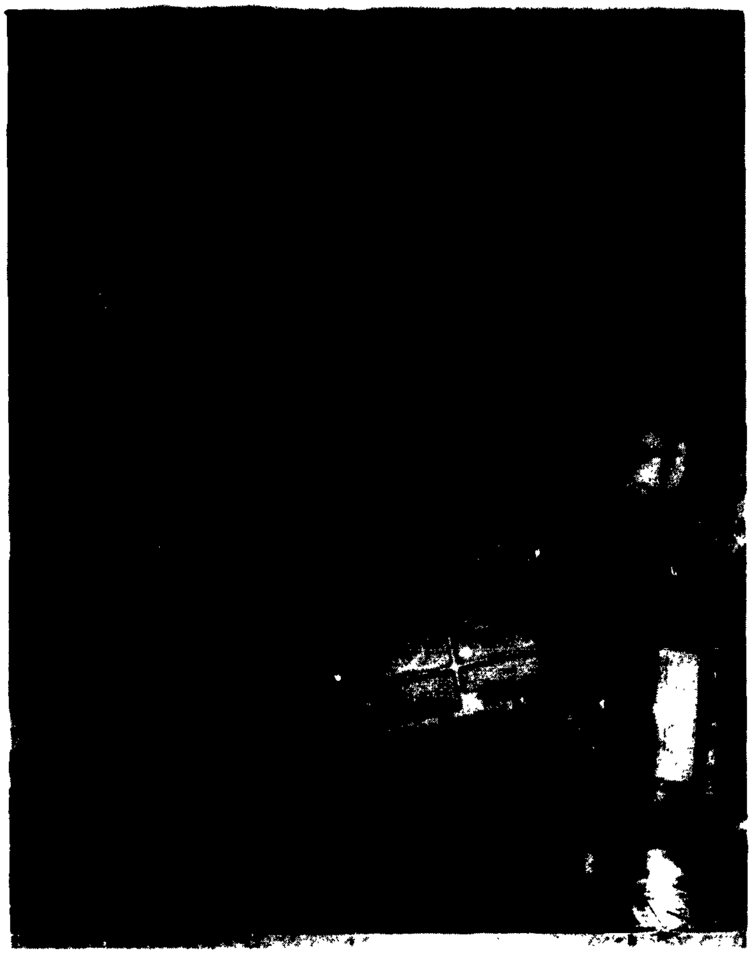


FIGURE 6. View through the right side of the helicopter showing the position of the amber acetate for "blackening" the view of the outside world.

For the contact portion of the experiment a section of the amber acetate immediately behind the combiner screen was made easily removable. When the amber acetate immediately behind the combiner screen was removed the subject's view (when wearing blue goggles) was restricted to the same solid angle of view of the outside world as that represented in the analogue display (Figure 8).

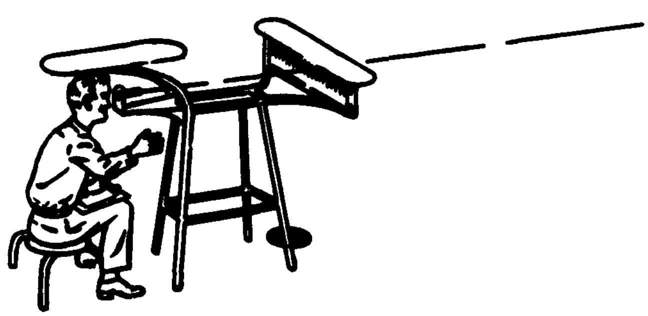


FIGURE 7. Observer Sighting Device

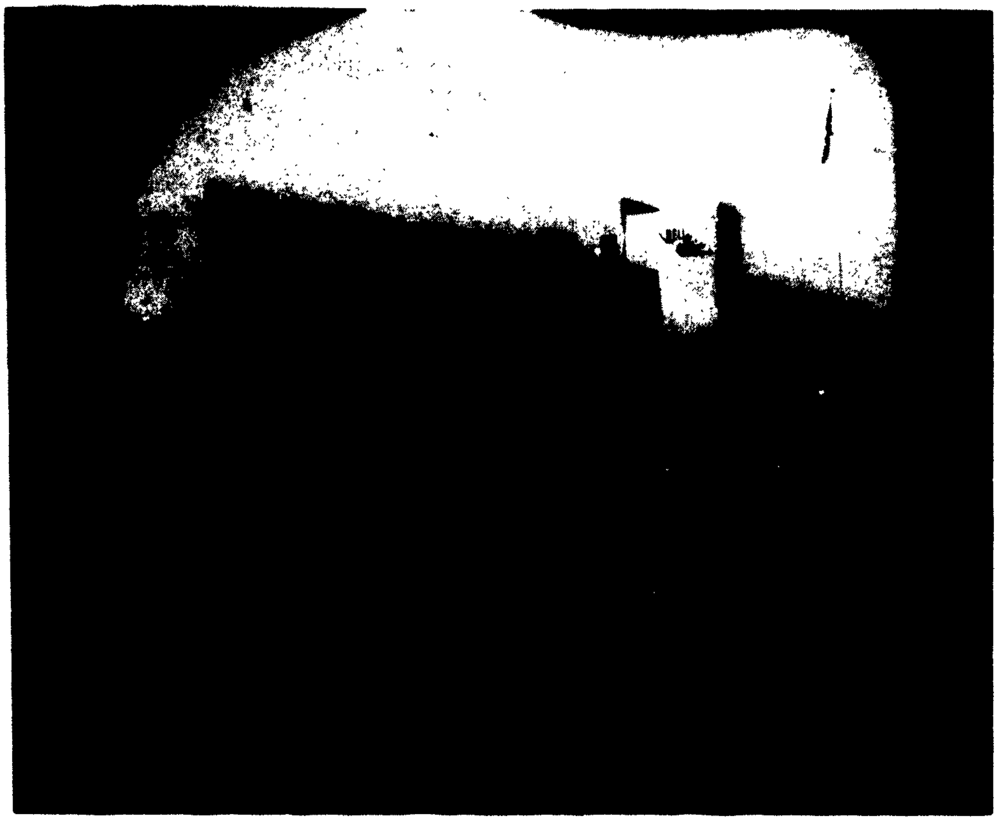


FIGURE 8. Contact Viewing Condition
From Subject Pilot's Position
In The RH-1.

The scoring equipment consisted of ground based sighting devices, stop watches and a C-2 compass indicator. The sighting devices were linear scales with a position sight as shown in Figure 7. The stop watches were used for timing purposes and the C-2 compass indicator was used by the experimenter/safety pilot as a reading device for recording heading changes.

A Century Model 409 oscillograph with a paper speed of one inch per second was used for recording deviations about the various parameters under study.

A cross-pointer instrument which displayed X and Y position was installed on the experimenter/safety pilot's side for setting the hovering position symbol at the zero position after each 2-minute trial. Before the start of each recording session a set of synchros were used to "zero" pitch, roll and heading while hovering.

Procedure

The subjects were scheduled to appear at hourly intervals. At the beginning of the test session they were given the following set of instructions while sitting in the helicopter looking at the display:

> "The purpose of this test is to determine how well a group of qualified helicopter pilots can hover under simulated instrument conditions using the grid display before you. The display is tied directly to the ground in a 1:1 relationship; therefore, if the squares of light appear to be moving away from you the helicopter is drifting backwards. In the center of the display notice the large square of light. It is the square or spot you are to keep in the center of the display. It actually represents a 16 foot square "pad" on the ground. If the square moves off the display you are to try and get it back.
>
> "Now notice the vertical display at the left center of the combiner lens. This is a display of your absolute altitude above the ground. The center of the waist represents seven foot altitude and will be your hovering altitude. The entire scale represents 16 feet. When the scale is completely blacked out, you are at some altitude above 16 feet.
>
> "The helicopter will be established in a hover on the proper heading, altitude and position. On signal you will take all controls and hold this hovering position for two minutes. You will be given six of these two minute trials. Before the start of the first trial you will adjust the pitch indices to the top of the horizon line while the ship is in a hover. When they are aligned to your satisfaction the display will be set up for the first trial.
>
> "Do you have any questions?"

After the instructions were given and all questions answered the subjects were requested to put on the blue goggles. While becoming adapted they were shown the proper position in which to hold their head for optimum viewing of the display in the "knothole". The experimenter then put the helicopter in a hover and instructed the subject in adjusting the pitch indices to appear coincident with the top of the horizon line. The helicopter was then landed and set up for the first trial. The hovering position symbol was centered through the cross-pointer display on the experimenter's panel by switching out the doppler signal to the belts and slewing them to the zero hover position. The doppler signal was turned on and the helicopter put into a hover with the hover symbol at zero, the heading on zero (cardinal with the grid lines), and the absolute altitude display at the center position (7 feet altitude). With all parameters stabilized, the subjects were told to take all controls and maintain the hover. The recorder was then turned on and timed for two minutes. At the end of each two-minute trial the experimenter took over control of the helicopter, returned it to the starting point and set up the displays and recorder for the next trial. After the sixth trial each subject was given the opportunity of taking the helicopter off, establishing a hover, and landing while still on the contact analog.

For the contact hovering task the subjects were given the same instructions as were given for the instrument task, with the appropriate changes to fit the contact case. The experimenter/safety pilot established the helicopter in a hover into the wind using a set of external referents for standardizing the hovering position from trial to trial and subject to subject. The subject's task was to hold a fixed hovering position (constant altitude, heading, fore-and-aft and lateral position) for two minutes. Data were recorded at 10-second intervals throughout the six trials for the parameters on which performance was desired. With the helicopter established in a hover at approximately 7 feet altitude the subject was given control. After 10 seconds a signal was given to a ground observer, who in turn gave a signal to all observers to start recording data.

All subjects were tested first under instrument conditions, and then brought back for testing under the contact condition. The condition designated "instrument" was the analog display as shown in Figure 4.

RESULTS

The data as recorded were reduced to 1) a constant error statistic

$\frac{\Sigma /X/}{N}$ and 2) a variance of the error about the standard (RMS) $\sqrt{\frac{\Sigma X^2}{N}}$

for analysis of each of the parameters of pitch, roll, yaw, heading and lateral and fore-and-aft deviations. Since the standard is zero, Σ X, in the contact case, is the sum of the 12 scores obtained through recording deviations in each of the parameters measured at each 10-second interval during a 2-minute trial and, in the instrument case, is the sum of 40 scores taken at 3-second intervals from the oscillograph record during a 2-minute trial. The constant error for any one subject was obtained by summing absolute errors for the 12 measurements per trial in the contact case and 40 measures per trial in the instrument case, averaging the measurements to obtain the trial CE, and averaging the trial CE's for the CE for the subject. A summary of the analysis is shown in Tables 1 and 2.

Constant Error Analysis

The constant error analysis showed that any constant bias from the standard present in the data of the two conditions over all trials and for trial 6 could be attributed to chance (Table 1). That is to say that the average deviations from the standard for all parameters measured were not significantly different from zero, and thus were random or chance deviations.

TABLE 1.

SUMMARY OF CONSTANT ERROR DATA

(Altitude, Fore-and-Aft, and Lateral deviations given in feet; Heading deviations given in degrees.)

	SUM OF ALL TRIALS, 1 THRU 6				TRIAL 6			
	Instrument		Contact		Instrument		Contact	
	$\bar{X}'$	σ'	$\bar{X}'$	σ'	$\bar{X}'$	σ'	$\bar{X}'$	σ'
Altitude	1.10	.40	.33	1.04	.10	.40	.25	.92
Fore-and-Aft	5.66	12.45	2.00	2.42	7.92	14.15	1.38	3.04
Lateral	5.28	7.20	.67	1.04	5.28	6.72	.17	.83
Heading	2.07	2.99	0	1.11	1.38	6.67	.17	1.83

NOTE: No statistically significant differences were found between the obtained constant errors and the standard for either contact or "instrument" condition.
$\bar{X}'$ Represents Mean RMS, All Subjects
σ' Represents SD about $\bar{X}'$

Variance About the Standard (RMS)

With respect to the control of altitude and lateral translation, differences between contact and the grid perspective display were found not to be significant. Performances were found to be significantly more variable in the control of fore-and-aft translations and heading deviations when the subjects were operating with the grid display (Table 2).

On trial 6 the variance about the standard on the control of altitude was significantly greater on the contact condition, whereas on the control of lateral and fore-and-aft translation the variance was significantly greater on the instrument condition (grid display). The control of heading was more variable on the instrument condition at the 5% level of confidence.

TABLE 2.

SUMMARY OF THE ANALYSIS OF THE VARIABILITY OF THE ERROR SCORES ABOUT THE STANDARD (RMS)

(Altitude, Fore & Aft and Lateral deviations given in feet; Heading deviations given in degrees)

	SUM OF ALL TRIALS, 1 THRU 6				TRIAL 6			
	Instrument		Contact		Instrument		Contact	
	$\bar{X}''$	σ''	$\bar{X}''$	σ''	$\bar{X}''$	σ''	$\bar{X}''$	σ''
Altitude	2.12	.53	1.66***	.78	1.67	.66	3.48*	1.52
Fore & Aft	24.34	11.23	7.06*	2.15	22.58	9.85	4.70*	2.47
Lateral	9.17	10.45	2.76***	1.57	5.09	2.93	1.87*	.59
Heading	7.41	3.36	3.23*	1.11	6.92	3.71	4.11**	1.51

* Significant at .01
** Significant at .05
*** Not significant

$\bar{X}''$ Represents Mean RMS; all subjects

σ'' Represents SD about $\bar{X}''$

DISCUSSION

This experiment was designed to determine the performance of experienced helicopter pilots in hovering the helicopter on simulated instruments using a grid encodement of the ground plane, and to compare this performance with contact performance, contact being limited to the same visual angle as that represented by the grid display. The results show that experienced helicopter pilots can hover without reference to the outside world when using a perspective grid pattern plus a horizon line to encode the ground plane and horizon. Further, although specific data is not presented, all subjects, plus eleven other experienced pilots, demonstrated the ability to take the helicopter off, establish a hover and land after six two-minute trials using the grid perspective display.

At no time during the testing period did the experimenter/safety pilot have to take over control. The same was true when landing and take-offs were made. Each landing and take-off was considered extremely safe due to the very small rates of movement over the ground. Many times the rates at touchdown were zero.

CONSTANT ERROR ANALYSIS

The constant error analysis for both total and final scores (Table 1) showed that the mean absolute deviation from the standard hovering spot was small and statistically not significantly different from a zero deviation. Had the pilot or the display, or any other component in the system, introduced a constant and significant amount of error, examination of the system to determine the source would be in order. In this system constant errors in the sensing equipment or display system could introduce a bias. This analysis shows that no significant bias was present.

VARIABILITY ABOUT THE STANDARD (RMS)

Analysis of Total Scores

The analysis of the variability of the error scores about the standard (Table 2) shows that there were no significant differences between performances under the contact and instrument conditions in the control of altitude and lateral translation. However, in the control of fore-and-aft translations and of heading, performances were more variable on the instrument condition than on the contact condition. The finding that the subject pilots could control altitude and lateral deviations as well using the grid perspective display as they could under contact condition is a significant one. Its significance is underscored when one considers the lack of sophistication of the grid display used in the study (Figure 4).

Even with such a crude mechanization of the grid perspective, subjects with little recent instrument experience (and much recent contact experience) could maintain lateral deviations and altitude as well with the display as they could on contact. The importance of recent instrument experience will be discussed later.

The relatively poorer performances on fore-and-aft and heading deviations using the perspective display needs further examination. It will be noted from Table 2 that fore-and-aft deviations were markedly greater than lateral deviations for both the perspective display condition and the contact condition. Two prime factors are felt to be important contributors to the large fore-and-aft error. First, during the conduct of the tests the aircraft was headed into the wind. Consequently, variations in wind speed acted as a disturbance directly upon the fore-and-aft parameter while it did not affect directly the lateral parameter. The pilot was thus presented with a more difficult control task in fore-and-aft than in lateral. Second, the perceptual discrimination problem is more difficult in the fore-and-aft dimension under the display condition used in this test. This problem in discrimination of the relevant cues for control of fore-and-aft translation was apparent in earlier vertical display studies.[4,5] These earlier studies tested the pilot's ability to hover the helicopter when his field of view was restricted to an 8x8" opening in the helicopter windscreen. Pilots were tested under conditions of binocular and monocular vision. Here also fore-and-aft deviations were markedly greater than were lateral deviations.

The visual discrimination problem is discussed in detail in reference 4. The essential point is that the pilot maintains fore-and-aft hovering position by keeping an object or objects in a particular relationship to an internal referent in the helicopter. Restricting his field of view to a small area directly in front of him reduces his ability to discriminate fore-and-aft changes. Figure 9 shows a side view of what happens in the discrimination task when an object is lost from the viewing area by a forward translation of the helicopter.

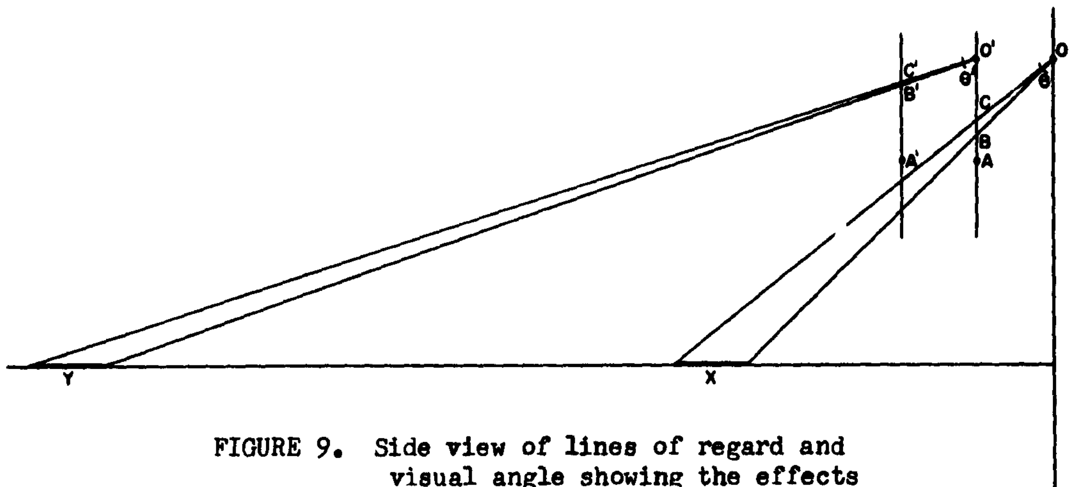


FIGURE 9. Side view of lines of regard and visual angle showing the effects of forward translation.

Assume the observer's eye (O and O') stays at a constant altitude, that object "y" is the same size as object "x" and lies approximately forty feet from "x" in the same plane, and that the bottom of the viewing area is at A and A'. When the observer's eye is at point "O" the area covered on the display is that between points "B" and "C". When the helicopter moves forward to O' and object "x" is lost from view, the observer is now discriminating fore-and-aft changes relative to object "y". The area covered on the display is now reduced to that of B'C'. This reduction of area reduces the "gain" of the display to the point that a larger deviation in fore-and-aft translation must occur before it can be discriminated on the display. It can also be seen that the visual angle (ø and ø') is affected adversely by the shifting of visual attention from object "x" to object "y". Zegers [7] states that an increase in motion parallax threshold occurs with an increase of distance from the observer to the viewed object.

Another factor affecting the discriminal task of the pilot while hovering is the task of determining a particular change in fore-and-aft position to be a true fore-and-aft translation. First he must differentiate a movement as being a fore-and-aft change, an altitude change, or a pitch change. It can be seen in Figure 10 that a change in altitude which changes eye position, O, and viewing area, A-B, to eye position, O', and viewing area, A'-B', will make the object C appear to move down the viewing area - a phenomenon which is also present when the helicopter translates forward. Thus a movement of an object down the viewing area is an ambiguous cue.

In like manner, ambiguity results when a change in aircraft pitch occurs. As with altitude changes, pitch changes result in changes in the apparent position of objects within the viewing area which are equivalent to those occurring with changes in fore-and-aft position. This situation is depicted in Figure 11.

It can be seen that the discrimination of fore-and-aft movement is relatively more difficult and is confounded with cues to other movements of the vehicle when the display area is reduced in size and positioned at eye level to the pilot. Performance in controlling fore-and-aft deviations can be improved by lengthening the display area in the vertical dimension to lower the pilot's line of regard and give him a view of the surface closer to the aircraft. In the earlier study [4] of pilots' ability to hover the helicopter under conditions of restricted viewing area, fore-and-aft control improved when the viewing area was enlarged in the vertical dimension. In that study changing the viewing area so as to

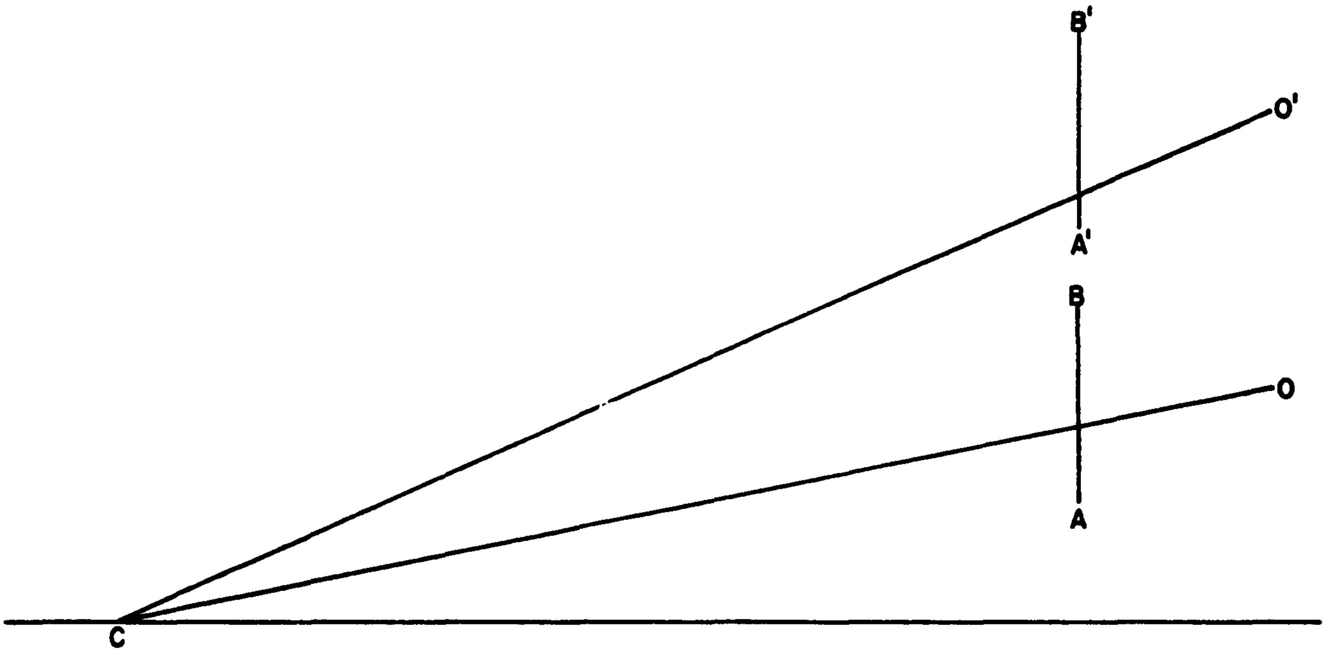


FIGURE 10. Side View of the Apparent Motion of Object C Down the Viewing Area with Change in Altitude of the Helicopter.

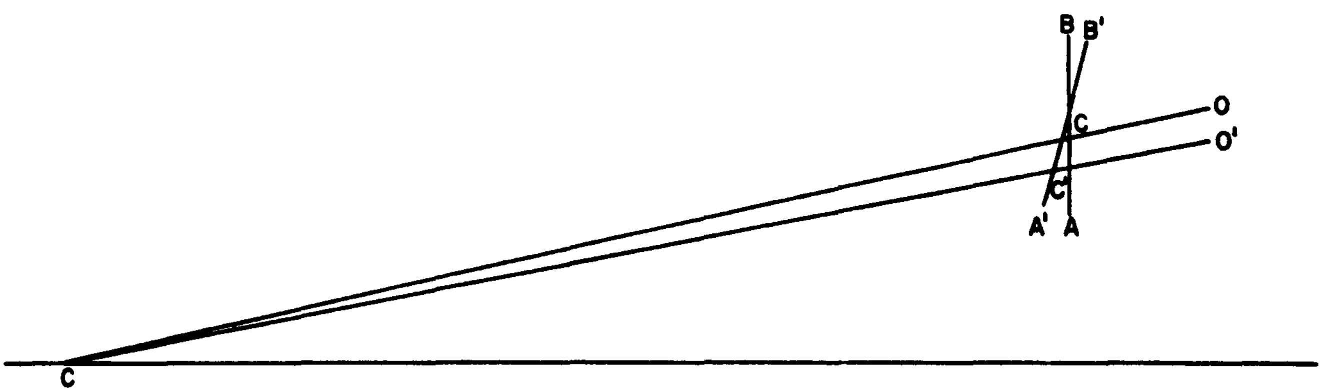
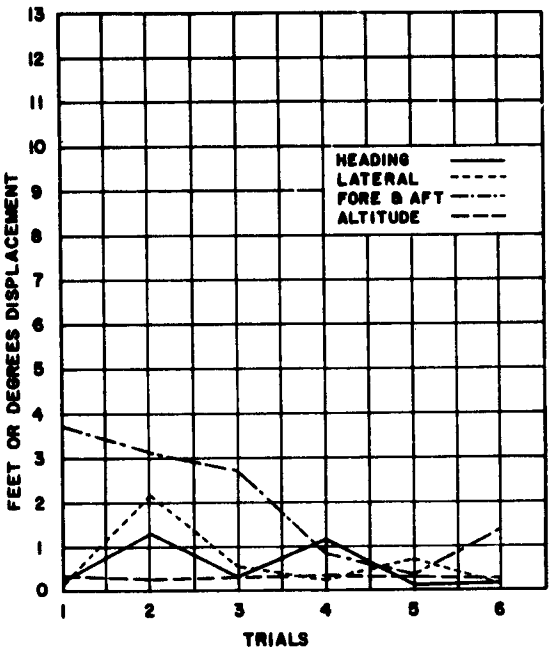
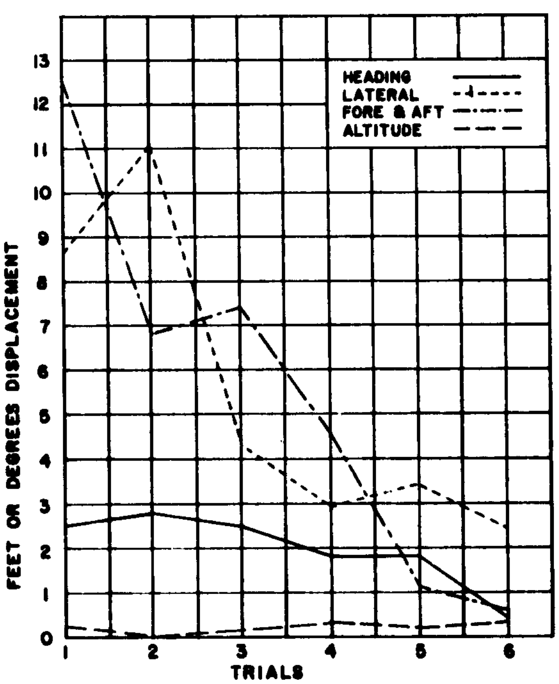


FIGURE 11. Side View of Lines of Regard Showing Apparent Change in Position of Object C on Viewing Area with Change in Pitch of the Helicopter.



CONTACT DATA
FIGURE 12. Learning Curves of Contact Error Scores Reduced to Feet or Degrees



INSTRUMENT DATA
FIGURE 13. Learning Curves of the Instrument Error Scores Reduced to Feet or Degrees

change the maximum depression angle of the line of regard from 8° to 23° changed the variability score for fore-and-aft deviations from 12 feet to 9.8 feet.

Analysis of Trial 6

A look at the error scores on Trial six may be considered a more meaningful comparison of the subject's performance in the contact condition and instrument condition than the error scores over all the trials since performance has had an opportunity to become more stabilized. Inspection of the learning curves for both conditions (Figures 12 and 13) shows the error scores on Trial 6 to have reached approximately the same level for both conditions. The trend of the error scores on instruments (the grid display) is still decreasing for all parameters except altitude, which shows little fluctuation from trial-to-trial. Examination of the variability in performance on Trial 6 (Table 2) shows again that the control of fore-and-aft deviations is more difficult than is the control of lateral.

The interesting finding in the analysis of Trial 6 is that after a bit of practice these pilots were able to control altitude with less variability under the "instrument" conditions than they were under contact. A discussion of what has come to be known as "scan pattern" is believed to be pertinent to this finding.

The reader will recall that altitude was presented in the "instrument" condition by means of a thermometer type instrument (Figure 3). Pilots, being as they are, must attend to one parameter at a time for precise discrimination and control, brief as that time may be. Thus the pilot works out for himself a spatial and temporal pattern of visual fixations (information gathering) in order to bring about the best balance among all the parameters for control. The altitude information in the instrument or grid display condition was discretely separate from the "integrated" complex of the other five parameters, and, although "qualitative" in the sense that no numbers were displayed, provided a precise indication of error. With a small amount of practice these pilots were able to incorporate this precise information into their control so that they were less variable in the control of altitude using it than they were when using contact altitude information. It is, of course, not surprising that presenting information in more precisely readable form results in more precise control. The point to note is that the pilots were able to incorporate this precise form of information presentation into the context of the analog form of presenting the other five parameters and to use it with precision.

This finding is important in view of the fact that earlier studies (5) have shown that altitude discriminations are relatively poor when viewing a grid perspective display. Indeed, the reason for encoding altitude by means of a thermometer type gauge in the present experiment was a result of the earlier study and tests in the RH-1 which showed that it was not possible to discriminate altitude changes with this grid display. The more abstract and "symbolic" display of altitude was successfully combined by the pilots with the grid perspective display to the extent that after 12 minutes of practice variability in altitude held was less using these displays than was the case in contact flight.

Although it is clear from examination of the variability scores on Trial 6 that performance in the contact condition was superior to that using the grid perspective display for all parameters except altitude, the data show that a quite acceptable performance was attained using the grid display on all parameters with the possible exception of fore-and-aft control. It should be pointed out here that in hovering and landing the helicopter the rate of movement of the machine on contact with the ground is extremely important. Each of the pilots in the experiment plus eleven other experienced pilots were able to take the helicopter off, hover and land it successfully after six 2-minute trials.

The fact of the limited amount of practice (12 minutes) must not be overlooked. It is a matter of conjecture as to how much practice would be necessary to achieve maximum performance. It is felt that another six trials would have produced a set of learning curves which would be quite stable and in which instrument and contact curves would be closer together. It must be remembered that the pilots used in this experiment were highly practiced in contact flight but were not well practiced in instrument flight. We believe that instrument pilots with highly developed habits of scanning would be better able to control the grid display than were those with little instrument experience.

CONCLUSIONS AND RECOMMENDATIONS

This experiment was conducted to determine whether experienced pilots could control the helicopter during hover using a display with a perspective grid encodement of the ground plane with a broad line encoding the horizon and to compare this performance with that of contact flight. After six trials of two minutes each performance on the sixth trial showed performance in terms of RMS error to be significantly superior during contact flight in control of fore-and-aft and lateral translation, and slightly superior in control of heading. Control of altitude was superior under the instrument condition. Control of all parameters using the grid display was felt to be adequate for acceptable control even with this small amount of practice by pilots with little or no instrument proficiency. Given helicopter the rate of movement of the machine on contact with the ground is extremely important. Each of the pilots in the experiment plus eleven other experienced pilots were able to take the helicopter off, hover and land it successfully after six 2-minute trials.

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The experiment also demonstrated that a more abstract or symbolic type of display encodement (the altitude display) could be used in conjunction with the analog type of integrated display.

REFERENCES

1. Matheny, W. G., and Hardt, H. D., The Display of Spatial Orientation Information, Bell Helicopter Co., ANIP Report D228-421-001, Contract Nonr 1670(00), August 1959.

2. Matheny, W. G., and Hardt, H. D., Further Study in the Display of Spatial Orientation Information, Bell Helicopter Co., ANIP Report D228-421-002, Contract Nonr 1670(00), August 1959.

3. Wilkerson, Lowell E., and Matheny, W. G., Discrimination and Control of Pitch, Roll and Yaw with a Grid to Encode the Ground Plane, Bell Helicopter Co., ANIP Report D228-421-003, Contract Nonr 1670(00), January 1960.

4. Wilkerson, L. E., and Matheny, W. G., Some Factors Bearing on Size, Shape and Placement of a Vertical Analog Display Presenting Hovering Information, Bell Helicopter Co., ANIP Report D228-421-006, Contract Nonr 1670(00), February 1961.

5. Wilkerson, L. E., and Matheny, W. G., A Study of the Effects of Monocular Vision on Hovering Performance, Bell Helicopter Co., ANIP Report D228-421-007, Contract Nonr 1670(00), September 1961.

6. Fox, G. A., Hardt, H. D., and Matheny, W. G., Detection of Small Changes in the Size of the Squares in a Grid Line Display, Bell Helicopter Co., ANIP Report D228-420-002, Contract Nonr 1670(00), February 1959.

7. Zegers, R. T., Monocular Movement Thresholds as Functions of Field Size, Field Position, and Speed of Stimulus Movement, Journal of Psychology, Vol. 26, pp. 447-49, 1948.